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SOME ASPECTS REGARDING THE IMAGE ACQUISITION USING VIDEO SYSTEMS UNDER LOW VIBRATIONS

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Rezumat. *Autorii analizează posibilitatea de evaluare a calităţii imaginii preluate prin intermediul unui sistem de achiziţie video aflat în regim de vibraţii scăzute, fără stabilizare, respectiv cu stabilizare electronică. Calitatea imaginilor statice a fost cuantificată prin rezoluţie, claritatea contururilor şi contrast. Deplasările din imagine dintr-o secvenţă video, achiziţionată cu o cameră CCD, au fost analizate prin calculul gradului de corelare dintre imaginile extrase din cadre. Regimul vibratoriu al camerei video utilizate a fost caracterizat prin frecvenţă şi amplitudine şi a fost studiat cu ajutorul unor programe software de analiză sunet şi imagine. În lucrare sunt prezentate imagini reprezentative ale obiectelor test utilizate, înainte şi în timpul vibraţiilor, precum şi rezultatele determinărilor efectuate. S-a constatat că parametrii vibraţiilor influenţează diferenţiat parametrii cuantificabili ai calităţii imaginii.*

Abstract. *The authors analyze the possibility of evaluating the image quality taken by a video acquisition system under low vibrations, without and with electronically stabilization. The quality of some static images was quantified by resolution, sharpness contours and contrast. The image displacement in a video sequence taken with a CCD camera was analysed by calculating the correlation's degree between extracted frames. Vibratory conditions for video camera used were characterized by frequency and amplitude and were studied by sound and image analyzed software. Representative images of test objects used are presented in the work, before and during vibration and the results of measurements performed, also. It was found that the vibration characteristics have a differentiated influence on measurable parameters of image quality.*

Keywords: Image quality, data analysis, low vibrations, driving devices, thermal cameras, CCD cameras

1. Introduction

The image quality when unexpected events are occurred is essential in vehicles driving and traffic monitoring during day or night, if the driver uses thermal cameras and CCD cameras. Most of the difficulties are due to the stress growing that is induced by an increased attention needed to drive and maintain the carefulness to avoid accidents. Mechanical vibrations are among the most powerful degradation sources of image quality and they can lead to the distraction of driver's attention.

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The visual image gives to the driver the greatest amount of useful information. Currently, analysis procedures based on high resolution image acquisition, its interpretation and processing allow convenient quantification and analysis of some phenomena and processes from various disciplinary areas. There are two types of image degradation caused by vibration of the camera.

The first is the vibration of the sight line, causing location changes of the scene in successive frames.

The second degradation type is the blur induced in each frame of the sequence due to motion during the exposure [1].

An area of particular interest is to assess the low-frequency mechanical vibrations on image quality video taken with sensor array systems in VIS and IR. Analysis indicate that even low frequency vibration greatly affects the predicted target detection times and ranges.

Mechanical vibrations, especially those with low frequency and high amplitude are often the cause of image degradation. An example of low vibrations source is given by the turnover of a land vehicle equipped with image display systems. Another example is that given by the air movement of an UAV (unmanned aerial vehicle), also equipped with similar systems for image acquisition and transmission.

This work has as target for study the first of two issues mentioned, namely vibrations generated by road travel of a vehicle.

2. Approaching the idea

The main causes of generating vibrations are the engine, the bumps or the roughness of the land on which the vehicle is moving. In most of these cases, vibrations have a frequency range below 20 Hz. Under the impact of vibrations, the images seen on the observation display become unclear, contours are not clearly defined, the contrast and image resolution are decreasing.

The result is a significant deterioration on the image quality and on the possibility of recognizing objects on the ground. Low temporal-frequency mechanical vibrations involve random image degradation that depends on the instant of exposure [2]. Mechanical stabilization is not enough, and therefore is imposed an electronic stabilization too, with a more sensitive reducing effect.

The vibrations produce a blurred image. If the motion is slow compared to the integration time or processing time, the target does not appear to have blurred edges [3]; on the contrary, if they are of the same magnitude the vibration influence becomes significant.

Motion affects the ability to resolve details. As the speed increases the edges becomes fuzzy with the motion, the edges become less distinct [3]. The engine's vehicle and the road roughness can induce a sinusoidal motion. Commercial CCD and thermal cameras have the frame frequency of 30 Hz, so close to the range of vibrations during walking. The eye's integration time is 0.1 s (10 Hz), comparable with both cameras and vibrations.

The vibrations of the video system on a moving vehicle are strongest as the roughness, road bumps and vehicle speed are higher. The direction of the vibrations is both on vertical and horizontal (on the same movement direction), more as the vehicle speed is permanently changing. As is appreciated in work [5], the range of vibration is in the 1.42 Hz÷5.7 Hz range at speeds of 100 km/h, both on the longitudinal and the vertical direction of the travel route.

Generally, at usual speeds, the vertical vibration frequencies are around 2 Hz÷10 Hz and on the movement direction are around 2 Hz÷20 Hz (fig. 1-2). The authors of the present paper consider that it is necessary to take into account the combined effect of these vibrations.

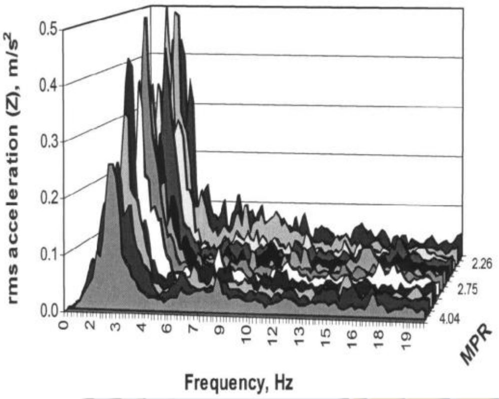


Fig. 1. Acceleration spectra in the vertical direction (*z*)

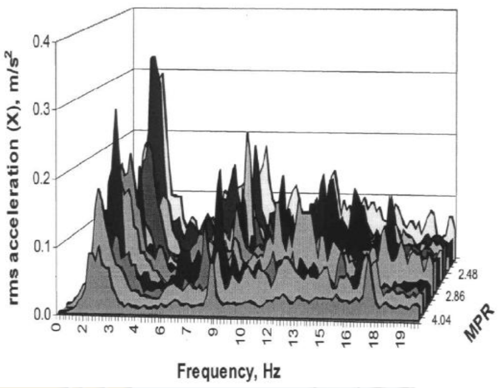


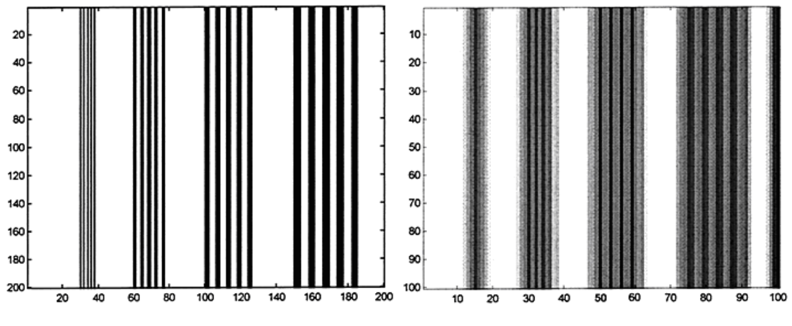
Fig. 2. Acceleration spectra in the the direction of travel (*x*) (before and after).

The present paper deals with two problems:

- an assessment of a static image quality acquired with a CCD camera in a vibratory regime;
- a comparative quantification of the vibrations influence, on a video acquired sequence, by an image analysis.

3. Methodologies and Proposed Solutions

An estimation of the vibrations influence can be realized by analytical methods or by the image analysis; these solutions are exemplified in many papers [5-10]. A convenient and usually approach is the use of patterns [2] putted on vibration stands and its image acquisition at different frequencies (fig. 3).



(a) (b)

Fig. 3. a) Bar target composed from vertical bars at frequencies 1/2, 1/4, 1/6, and 1/8 lines/pixel. **b**) An image from a sequence distorted by severe horizontal vibration (vibration amplitude of 15 pixels, frequency of 5 Hz).

The authors show two possibilities of test and analyse of these results and address to that research which refers at the image quality acquired with CCD cameras used on vehicles with displayed image field; the vibration shape is presented in fig. 4.

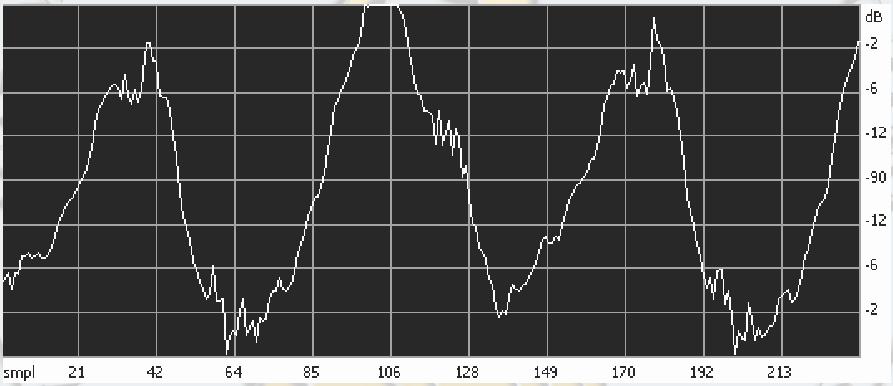


Fig. 4. The shape of low vibrations used at tests.

The results are based on the behaviour analysis of a pattern with horizontal and vertical bar models by different sizes and spatial frequency and also on the study correlation of digital images. This type of models simulates better the specific of the vibration directions on the vehicle. Therefore the authors consider as object of analysis the USAF 1951 type pattern in static conditions (fig. 5a) and in dynamic ones (fig. 5b). Groups of each parallel lines simulate the direction of above mentioned acceleration and the different sizes (resolutions) allow the analysis of different frequencies vibrations.

The authors consider relevant the study of image contrast before and after pattern vibration and also the study of Pearson correlation coefficient, as analyse instruments. As an example of this work methodology is taken into account only one behaviour pattern type. One can note that the pattern vibration cause blurred image perception and a decrease of its contrast (fig. 5b).

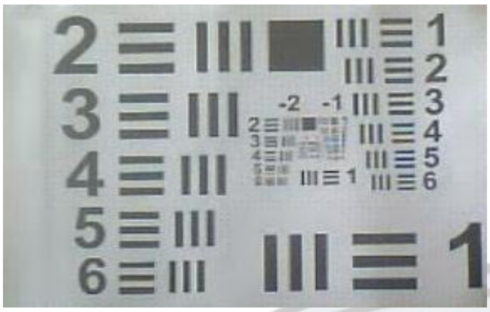


Fig. 5.a USAF pattern without vibrations.

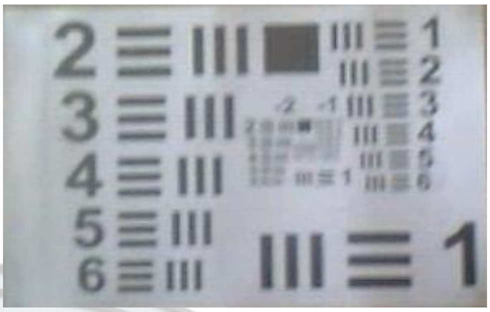


Fig. 5.b USAF pattern with vibrations.

A convenient form to quantify the blur due vibration is the optical transfer function (OTF). The formulation of the image distortion into an OTF-type format is practical for analysis and design of imaging systems [7].

Exact image degradation requires the calculation of a specific optical transfer function unique to the motion in the image [2].

Typically, an imaging system is subjected to linear and sinusoidal motion simultaneously (only for low frequencies), so the optical transfer function $\text{OTF}_{\text{motion}}$ is possible to be written as [11]:

$$\text{OTF}_{\text{motion}} = \text{OTF}_{\text{linear}} \cdot \text{OTF}_{\text{sinusoidal}} \quad (1)$$

which emphasizes the existence of three different forms of motion: linear, sinusoidal and random.

1. A first possibility to analyze the image motion during vibration is the contrast determination in image, along an arbitrary line drawn in the pattern image acquired with the CCD camera. The contrast is determined by highlighting the grey levels between the background and the pattern without vibrations (fig. 5) and also between the background and the same pattern under different vibration conditions (fig. 6-7).

Similar, one can see the pattern which is at the observability limit. It can be establish the resolution in the static image and the resolution during vibration for different amplitudes.

If it is considered the relative motion between the object and the CCD camera in the form of a sinusoidal vibration, as shown in the papers [2, 11]:

$$x(t) = A\sin(\omega_0 t) \quad (2)$$

where A is the amplitude, $\omega_0 t$ is the angular temporal frequency of the vibrations, and $x(t)$ is the relative displacement between the bar of the pattern image and the optical axis of CCD camera; beginning at time t_s and ending at time t_s+t_e, it obtain the figure 6 [2].

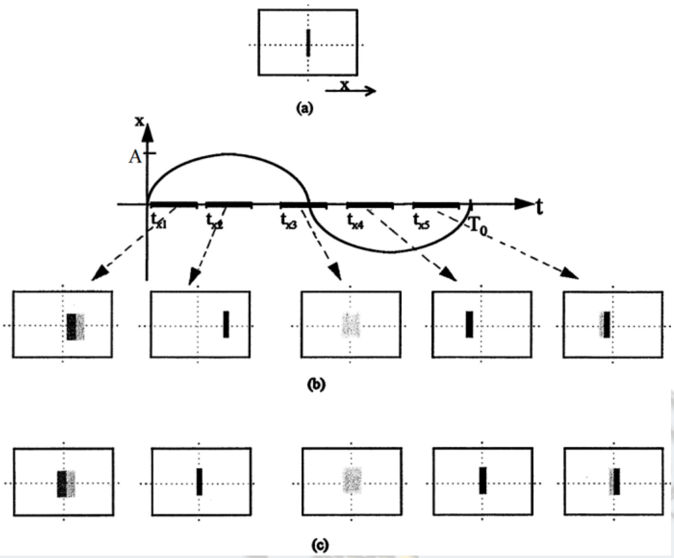


Fig. 6. (a) Original image (the vertical bar); (b) Images taken at different instants of exposure (t_{x1}–t_{x5}) exhibit different blurs and different shifts. (c) The centralized (no shifted) blurred images.

The value of t_e is measured from the instant the CCD camera is first exposed.

$$\mathrm{OTF}(f) = \int_{-\infty}^{\infty} \mathrm{f}_x(x) \cdot \mathrm{e}^{-2\pi \mathrm{f}_x} dx \tag{3}$$

where f is the spatial frequency, $\mathrm{f}_x(x)$ is the Probability Density Function or the histogram of $x(t)$. The lower and the upper limits, respectively, for x are results of minimum and maximum displacement between pattern image and sensor.

2. The second possibility of determining and analyzing the image displacement during vibrations is the study of the correlation's degree for a sequence of extracted images (frames) from a video. The study is made by appropriate software for analysis.

"The correlation" is a statistical technique by which it can be shown how strong are connected between them a pair of variables or, in other words, against an initial variable, considered to be original, what extent other variables by the same type are identical, similar or completely different.

In this case, the considered variables are pair of images (frames) extracted both by videos in which the pattern is under vibrations and by videos where the image was stabilized.

In the following, to see how the image instability was taken by the hardware system and software applied, the correlation coefficients obtained, R, are compared in these entire work hypothesis (vibration, stabilized vibration, without vibration).

Based on the above stated, it can be assumed that, for a video in which the pattern wasn’t under vibration, the images extracted by the movie should be identical.

So, over the first frame considered original (frame 1), all the other pairs of type as frame 2/frame 1, …, frame *n*/frame 1 should be completely correlated.

By contrary, in the case of a pattern under vibration, as the characteristics of vibrations are changing, the frame pairs considered above should be only partially correlated, the differences being the strongest as the vibration amplitude increases, for example.

The image vectors can be expressed as $X_k = (x_{1,k}, x_{2,k}, ... x_{N,k})$ and $Y_k = (y_{1,k}, y_{2,k}, ... y_{N,k})$, where the values $x_{i,k}$ and $y_{i,k}$ are the average intensities of pixels in both images and $N = nxm$ is the number of pixels associated to each image.

The correlation coefficient R_k for a pair of variables $X_k(x)$ and $Y_k(y)$ can be written as [13]:

$$R_k = \frac{\sum_{i=1}^{N} (x_{i,k} - \bar{x}_k)(y_{i,k} - \bar{y}_k)}{(n-1)\sigma_x \sigma_y} \tag{4}$$

where

$$\overline{x_k} = \frac{1}{N} \cdot \sum_{i=1}^{N} x_{i,k} \quad \text{and} \quad \overline{y_k} = \frac{1}{N} \cdot \sum_{i=1}^{N} y_{i,k}$$

are the averages of values $x_{i,k}$, respectively $y_{i,k}$, and

$$\sigma_x = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(x_{i,k} - \bar{x}_k\right)^2} \quad \text{and} \quad \sigma_y = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(y_{i,k} - \bar{y}_k\right)^2}$$

are the standard deviations of images X_k, respectively Y_k, for each pair of considered images.

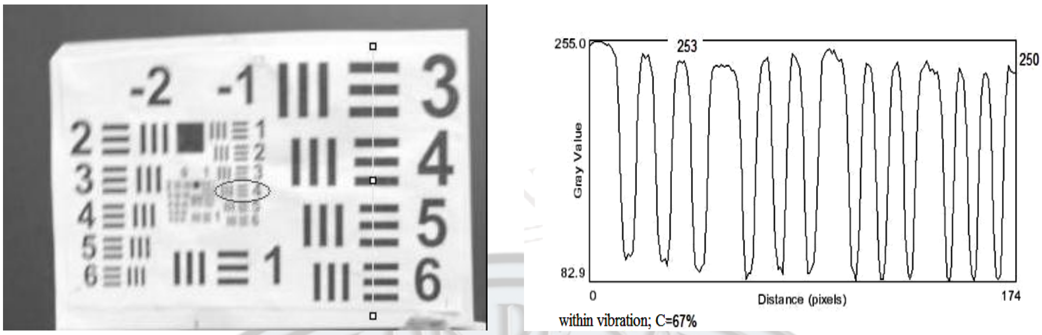
The correlation coefficient Pearson can take values between +1 and −1; as it is nearest to these values, the variables (images) are more correlated.

4. Experimental results obtained by image analysis along a line drawn on a representative area of the image (the pattern)

The images shown in figures 7 are acquired images of an USAF pattern without vibrations and during vibration surprised by the CCD camera that were made.

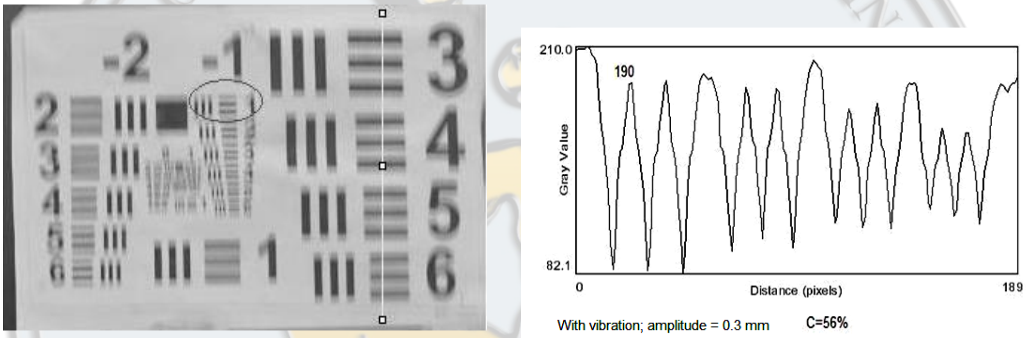
The shapes of pixel intensity variation in image with a calculated value of contrast are presented too.

The methodology has been presented in Chapter 2.



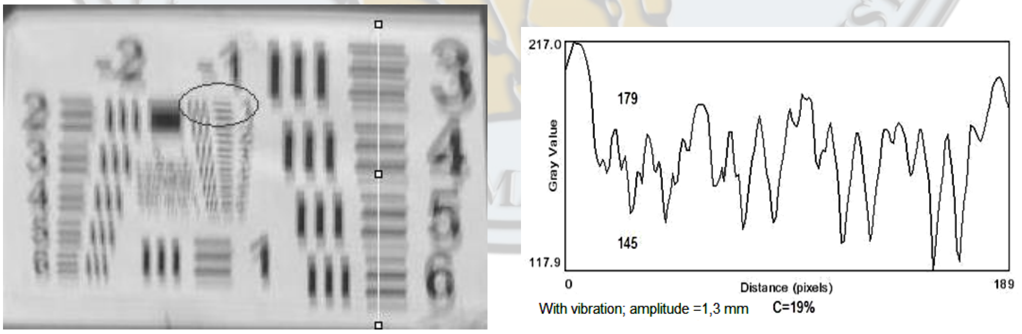
a) b)

Fig. 7. The acquired image of an USAF pattern without vibrations (a) and the shape of pixel intensity variation in image with a calculated value of contrast of about 67% (b).



a) b)

Fig. 8. The acquired image of an USAF pattern under vibrations with an amplitude of about 0.3 mm (a) and the image shape of pixel intensity variation with a calculated value of contrast of about 56%.



a) b)

Fig. 9. The acquired image of an USAF pattern under vibrations with amplitude of about 1.3 mm (a) and the image shape of pixel intensity variation with a calculated value of contrast of about 19%.

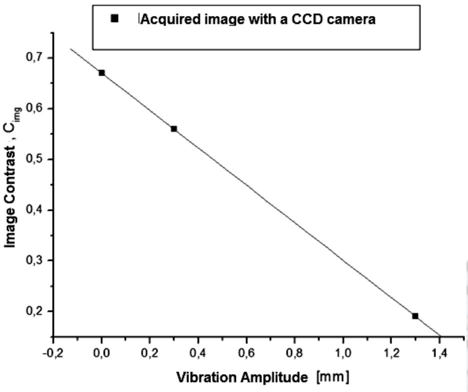


Fig. 10. The contrast is decreasing with amplitude vibration increasing in static image.

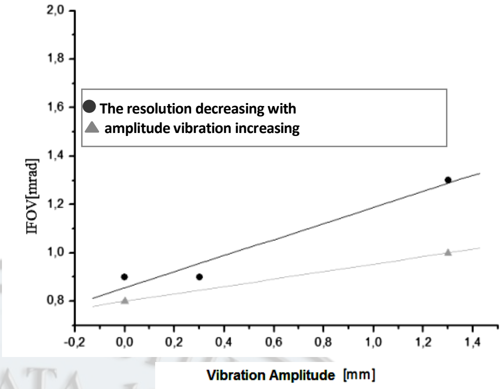


Fig. 11. The resolution is decreasing as result of instant visual field increasing IFOV [mrad] and amplitude vibration increasing too, in static image.

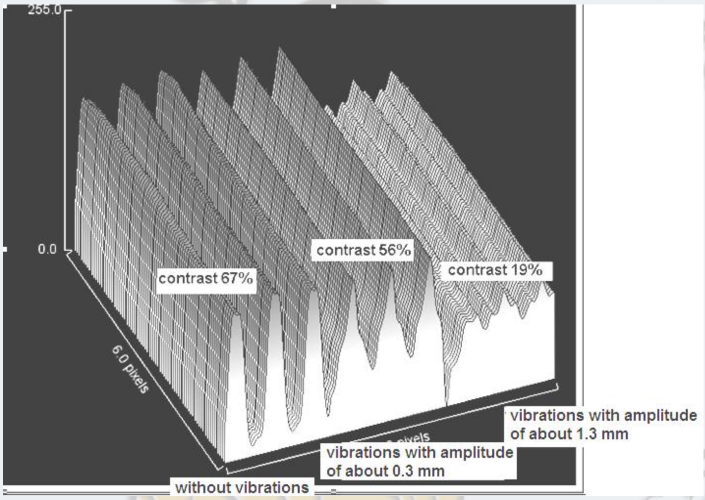
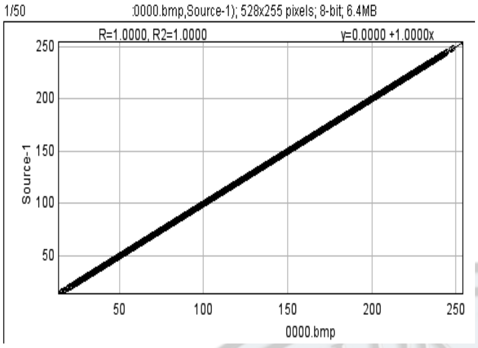


Fig. 12. Results of comparative experiments with the acquisition of images at different amplitudes of vibration, a spatial plot.

5. Results obtained by analysing the Pearson's correlation coefficient

The algorithm of correlation between images can take into account the entire package of images of the considered video, in vibratory conditions, stabilized or not.

By progressive comparison, starting from the first frame, for example, considered as origin for the entire sequence of images, with each video progressive frame, one can determine the correlation coefficients for each pair of images. Their analysis offers interesting possibilities of development. For example, in this case, one can easy see the periodical character of this coefficient, the spread of points varying more or less with the characteristics of vibratory conditions. This is exemplified in the correlation graphics obtained during 6 successive frames (fig. 13÷18).



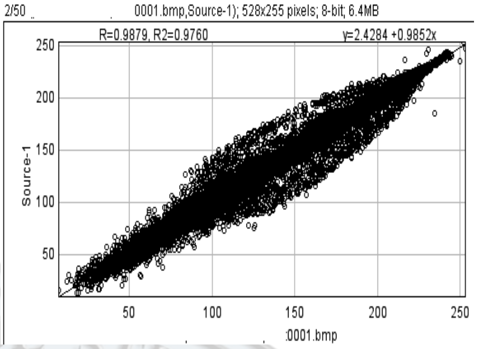
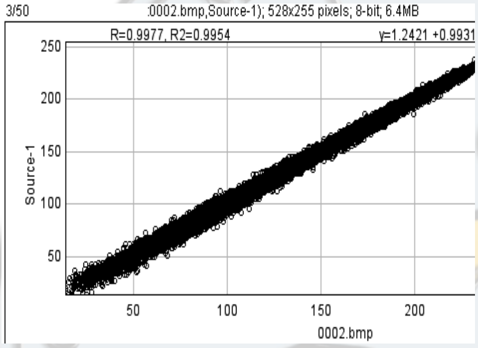


Fig. 13. Ideal correlation for a pair of 1/1 frames.

Fig. 14. Correlation obtained for the pair of 1/2 frames.



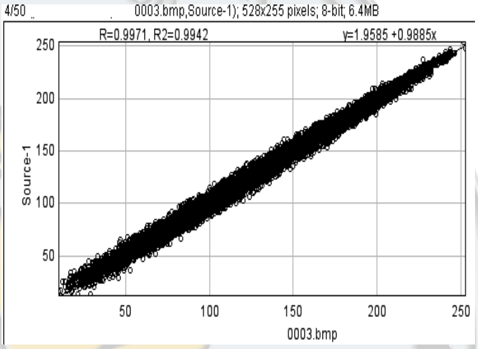
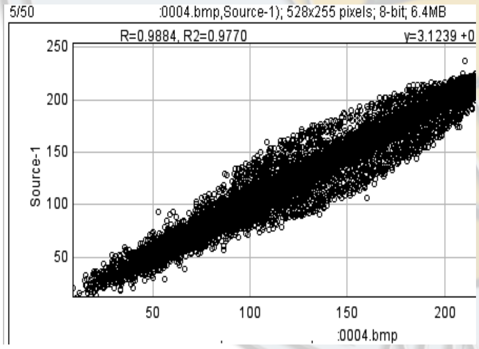


Fig. 15. Correlation obtained for the pair of 1/3 frames.

Fig. 16. Correlation obtained for the pair of 1/4 frames.



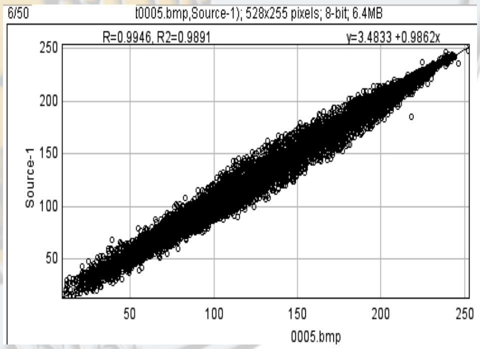


Fig. 17. Correlation obtained for the pair of 1/5 frames.

Fig. 18. Correlation obtained for the pair of 1/6 frames

Also, the variation of correlation values obtained in a video with 50 frames, highlights some specifics of the analysed vibrating (fig. 19÷ 20). One can see that towards the ideal case where is no vibration (fig. 19), after an electronic stabilization the differences between images are equalized with about 50% and this can be suggestively represented by this analyse image method (fig. 18-19) even if the numerical differences which appear are visible only at the 3rd or the 4th decimal.

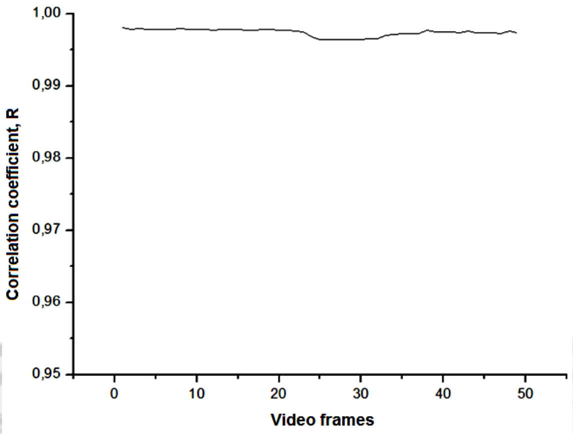


Fig. 19. The variation of correlation coefficient *R*, in the ideal case of a video in which the pattern isn't under vibration; the average correlation value is *R*=0,998.

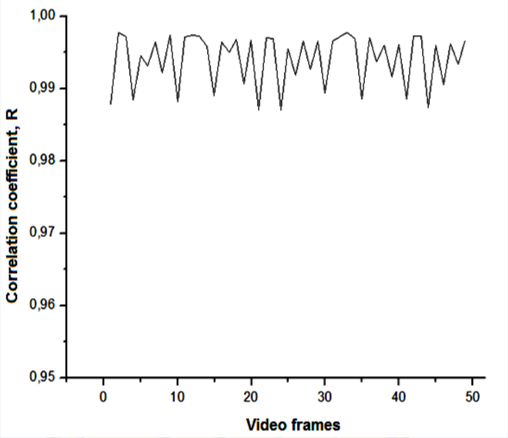


Fig. 20. The variation of the correlation coefficient *R* for a video with a pattern under vibrations; the average correlation value obtained is *R*=0,9926.

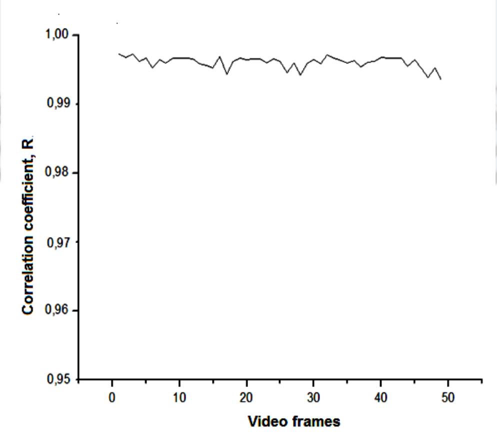


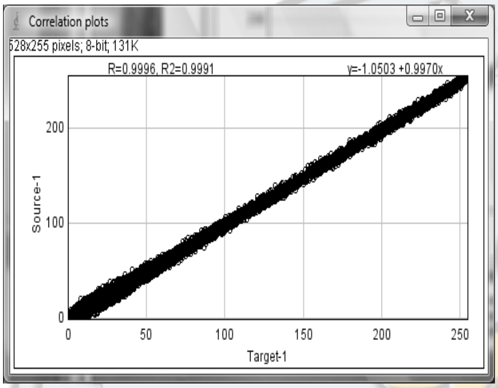
Fig. 21. The variation of the correlation coefficient *R* for the same video with pattern under vibrations, but stabilized by software; the average correlation value obtained is *R*=0,996.

An example of correlation almost perfect (*R* value is 0.9996) is shown in fig. 22 because of the lack of vibrations.

The differences here are because of pixel glows and the noise given by electronic components, especially.

In fig. 23, a map of differences area is exemplified, for the same pair of images.

One can see that the pattern is very weak shaped because of insignificant differences which appear.



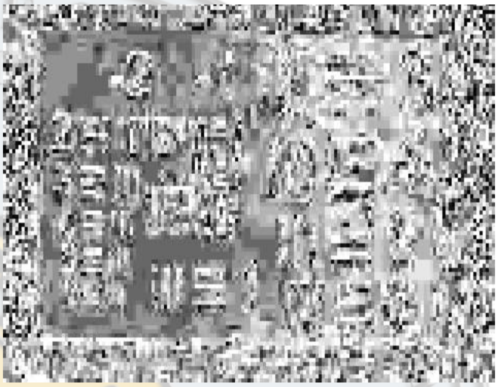
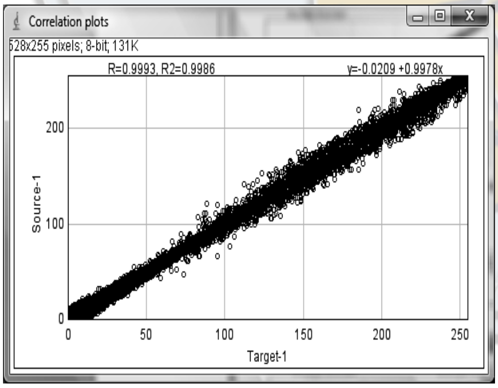


Fig. 22. The correlation diagram for a pair of frames without vibrations; *R*= 0.9996.

Fig. 23. Correlation map for a pair of frames without vibrations.

Examples of the results obtained for a pattern under vibrations are given in fig. 24 and 26, in different amplitude conditions; the correlation maps are also given for the same mentioned situations (fig. 25 and 27).



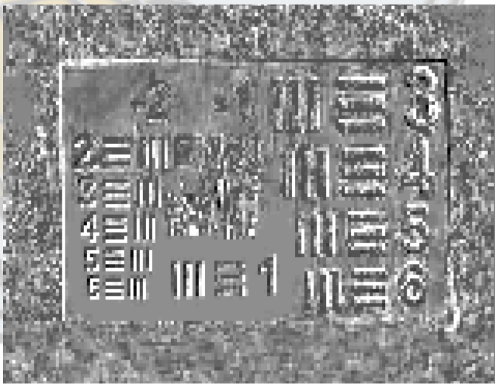


Fig. 24. Correlation diagram for a pair of frames where the pattern is under vibrations with low amplitude (0.2 mm) and relatively high frequency; *R*= 0.9993.

Fig. 25. Correlation map for a pair of frames under vibrations with low amplitude 0.2 mm; there are amplitude components on both *x* and *y* directions because both pattern shapes are equally highlighted.

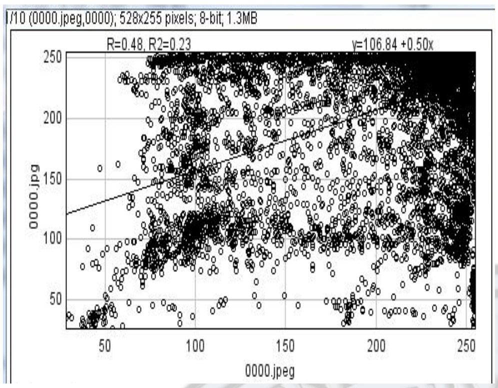


Fig. 26. Correlation diagram example for a pair of frames where the correlation is very low because of high amplitude vibrations (above 1 mm); the correlation coefficient is R = 0.48.

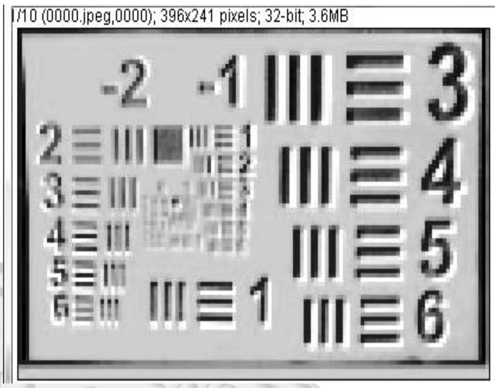


Fig. 27. Correlation map for a pair of frames where the correlation is very low because of high amplitude vibrations (above 1 mm); the pattern shape is very clear both for horizontal and vertical lines.

6. Conclusions

The accomplished study led to the following conclusions:

Evaluation of an image quality through a system under vibrations can be made by resolution quantification, contours sharpness and contrast image.

Increasing of vibration amplitude has as result a decreasing in image resolution and contrast and a lower correlation between pairs of frames in the same video.

If there are not vibrations the correlation coefficient is almost 1.

In a stabilized video the usual correlation value should be also near 1.

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